Opportunities to Improve the *Next Generation Science Standards* (the NGSS)

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Note: This white paper is also online at ImproveTheNGSS.org. Visit that website to download the paper, read our blog, or offer a comment. If you have colleagues who would be interested in discussing the NGSS, please send them that URL, ImproveTheNGSS.org.

Whatever their strengths may be, no set of education standards will be unchangeable, because society's needs and priorities change over time. In this discussion paper we suggest four areas in which national science education standards ought to be improved to better meet the needs of a democratic society.

Ours is not the first constructive criticism of the NGSS. For example, the *Journal for Research on Science Teaching* published a special issue in June 2018 focusing on the NGSS, noting that "constructive critiques are needed in order to guide the further evolution and implementation of the standards." An introductory editorial notes that some articles in the issue emphasize the need for the NGSS to focus more attention on "humanistic values of a democratic society," and others focus on strengthening the goal of students' "grasp of evidence" about science. These concerns are similar to our own.

In another constructive criticism, Harvard University Press recently published *How We Teach Science: What's Changed and Why It Matters*, by John L. Rudolph. His book explores the history of science education in the U.S. over more than a century. Considering the NGSS, Rudolph writes, "The current state of affairs makes one wonder if the move after World War II toward teaching science for the sake of science, characterizing it as something distinct and different from our everyday ways of living, is up to the task." It is clear that Rudolph wants to see science education put a much greater emphasis on the connections in a democracy between science and public policy, and "engender public respect for scientific institutions." We agree with these suggestions.

For us, a major impetus for writing this paper was concern about the proliferation of scientific misinformation. Currently, for example, the United States is experiencing the largest outbreak of measles in decades, due largely to many parents' mistaken belief that vaccines cause autism—despite high quality research showing that belief is not true. How can schools help students resist scientific misinformation? The national science education standards—statements of what children should learn about science in school—do not mention vaccines or immunization, nor do they suggest that teachers have a responsibility to help students investigate dubious scientific claims. Further, national science education standards and supporting documents do not provide teachers with adequate methods to help teach students to sort science fact from science fiction.

Based on such concerns, in this paper we suggest revisions to and/or new supplementary materials for the science education standards, whether nationally or at the state level. In this paper we discuss four important priorities that we believe are insufficiently addressed in current standards:

1. Include scientific misinformation as a topic for students to study;
2. Teach about the key role of scientific institutions in science (e.g., the CDC, the IPCC);
3. Broaden the view of "scientific literacy" embodied in the standards to include such important matters for citizens as the relation between science and public policy, how scientists develop confidence in their conclusions, and the ability to read and understand news articles related to science and engineering; and
4. Provide more information for teachers about key principles of teaching and learning, such as the importance of students' prior scientific misperceptions.

We believe these priorities could be addressed without significant disruption to the content of the science curriculum. For example, information about scientific institutions and attention to students' prior scientific misperceptions could, without difficulty, become part of existing units or lessons.

We aim to reach a broad and diverse audience with this paper, including not only science educators but also school board members, parents, public health officials, and politicians. This is a critical time for science and science education. Even as scientific knowledge continues to grow exponentially, and at a time when addressing key problems like climate change depends heavily on science, the CEO of the American Association for the Advancement of Science, the world's largest multidisciplinary scientific society, has expressed concern that fewer and fewer members of the public understand "the very idea that science is a special way for separating truth from falsehood" (Holt, 2017).

Before we explore the science standards' missing pieces and consider how the holes might be filled, we provide brief background information about education standards of all kinds. Next we introduce the national science education standards. Readers who are familiar with the history of American education standards in recent decades, and especially with the *Next Generation Science Standards*, might skip the next two sections and continue reading on page 5.

National Education Standards

Since 1989, when NCTM's *Curriculum and Evaluation Standards for School Mathematics* were published, education standards in many academic disciplines have become an important influence on what happens in American schools. Development of the various sets of standards, which rapidly led to the so-called standards-based reform movement across the United States, was conceived as a constructive response to splintered and poorly aligned state and local curricula, as well as to a growing political imperative in the 1980s and 1990s to improve American schools. As a result of efforts across all 50 states, education standards have had, and continue to have, an impact on curriculum, instruction, assessment, and teacher preparation. Of course, there are a great many other influences on students' learning—including their families and communities; experiences outside of school; the kinds of questions included on high-stakes standardized tests; and local resources such as equipment, teacher skill, and time devoted to teaching science. The quality of instruction still ranges from outstanding to dreadful. Moreover, in the United States, "national" standards are not mandates. States, districts, and even schools develop their own standards and detailed curriculum plans—but they usually do so using national standards as a guide. Therefore, it is fair to say that education standards have had a significant effect on what tens of millions of students in grades K-12 are taught.

The history of education standards developed since 1989 in multiple disciplines includes numerous revisions and additions, notably adding the influential Common Core State Standards for Mathematics and English/Language Arts, published for the first time in 2010. The Common Core, and especially standardized tests based on those standards, proved controversial. This is probably not surprising for any set of standards. Ongoing changes in national priorities and related educational approaches are to be expected, and the process of constructively re-examining education standards is fundamentally a healthy exercise, even though it may lead to heated debate.

An Introduction to the NGSS

The most recent set of standards for science education, the *Next Generation Science Standards* (NGSS) was published in 2013 and builds on earlier efforts. Those include *Science for All Americans* (1989), created by staff of Project 2061 at the American Association for the Advancement of Science. This significant book was followed by Project 2061's *Benchmarks for Science Literacy* (1994) and the *National Science Education Standards* (1996), which was published by the National Research Council of the National Academy of Sciences.

Work done since 1989 reflects not only perceived needs and priorities changing over time but changes in scientific understanding itself. Indeed, the document that served as the template for developing the NGSS, *A Framework for K-12 Science Education* (2012) published by the National Research Council, specifically notes that ongoing work on standards should be guided by "changes in scientific knowledge and priorities" (p. 311).

The current set of science education standards is national but was not developed by the federal government. Instead, development of the *Next Generation Science Standards* was a lengthy process involving more than two dozen states, the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and Achieve, a non-profit created in 1996 by a bipartisan group of governors and business leaders. As noted above, the NGSS built substantially on decades of earlier work. Also, *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas*, published by the NRC in 2012, was commissioned specifically to assist in developing the NGSS. As part of the process, Achieve studied education standards in ten countries to understand the expectations other nations have for student learning at different grade levels and in various subjects.

By 2019, 20 states[i] and the District of Columbia, which together include more than 41% of American students, had adopted the NGSS. In addition, more than 20 other states[ii], representing 43% of students, incorporated or adapted the NGSS into their own standards for science education. These data show that the standards are having some degree of impact across the great majority of American schools (Source: https://ngss.nsta.org/About.aspx.)

Many people, we among them, believe that the NGSS has multiple strengths. Past studies showed that the American science curriculum was "a mile wide and an inch deep." By limiting the number of topics to cover in science class, the NGSS seeks to replace the misguided emphasis on a great many discrete facts with a deeper understanding of fewer big ideas. Further, the NGSS aims to have more students "experience how science is actually done" (NGSS Executive Summary, p. 1). Another strength of the NGSS is making claim-evidence-reasoning the centerpiece of scientific explanations of phenomena, Finally, unlike its predecessor, the *National Science Education Standards*, the NGSS identifies climate change as an important topic for study. These are all admirable goals.

A notable characteristic of the NGSS is that it calls on teachers to teach three "dimensions" when teaching science or engineering. The first dimension is disciplinary core ideas, i.e. the most important elements of science content knowledge. There are about five dozen disciplinary core ideas (DCIs). An example of a DCI, in this case for third grade, is: "3-LS3-1, Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms." The second dimension is scientific and engineering practices, the methods used by scientists and engineers. NGSS identifies eight of these key practices, such as "analyzing and interpreting data" and "engaging in argument from evidence." The third dimension is cross-cutting concepts, each of which underlies a number of core ideas. The NGSS identifies seven cross-cutting concepts, including "cause and effect: mechanism and explanation," and "energy and matter: flows, cycles, and conservation."

According to the NGSS, these three dimensions are intertwined and should be taught together, not one at a time. For many teachers, this is an unfamiliar and difficult challenge.

Another notable characteristic of the NGSS is "raising engineering design to the same level as scientific inquiry in science classrooms at all levels." Thus, "the core ideas of engineering design and technology application" are given equal importance with core disciplinary ideas of physical, earth and space, and life sciences (NGSS Executive Summary, p. 1).

The NGSS is available free (www.nextgenscience.org). The standards run to hundreds of pages, including numerous appendices which are available online and published in print as a separate volume. In order to help teachers, the NGSS is available online in two versions, organized either by disciplinary core idea (DCI) for grades K-12, or by topic for grades K-12.

The NGSS influences practice directly because schools and school districts, principals and teachers, pay attention to their state's science education standards, and, as noted, most states have incorporated NGSS into their standards. But the NGSS also affects practice in other powerful, less direct ways. Publishers of science textbooks for grades K-12, ever attentive to what states and school districts will buy, try to align textbooks with state standards. If states require students to take high-stakes science tests, such as end-of-course biology tests, those tests are designed to align with state standards, which in turn are most often based on the NGSS—and teachers and students alike pay careful attention to topics they know will be tested. Authors submitting a manuscript for publication in journals for teachers published by the National Science Teachers Association (NSTA) are asked to specify how any topic they write about is aligned with the NGSS. The same is true for proposals to speak at NSTA conferences. Achieve manages a Science Peer Review Panel to identify and disseminate exemplary science lessons, which must be aligned with NGSS. The American Association for the Advancement of Science (AAAS) offers free workshops for teachers about curricula aligned with the NGSS.

These examples show that the NGSS influences science instruction in many ways. Major scientific and professional organizations, as well as state and local education agencies, spend time and money to support the NGSS. Similar to the way that a book featured in Oprah Winfrey's book club might see sales increase by millions of copies, scientific topics included in the NGSS and in major textbooks may have hundreds of thousands or millions more students study them, compared to topics not so highlighted. New and timely topics not addressed in the NGSS have a hard time penetrating this self-reinforcing and self-policing system.

Even without studies of the implementation or impacts of the NGSS—and it is time for such a study to be commissioned—it is reasonable to say that a large fraction of all K-12 teachers and students are influenced by what the NGSS recommends, whether or not they have read NGSS documents. The NGSS is not the one and only influence on practices in science classrooms, but it is the most important one. Therefore, it is vital to examine what the NGSS may be missing.

Priority One: Teach Students How to Resist Scientific Misinformation

In 2019 the World Health Organization (WHO) identified "vaccine hesitancy" as a top 10 threat to global health. Such hesitancy is based largely on scientific misinformation. According to the White House, climate change is simply part of a normal cycle—a claim that scientists know is not valid. Advertisements too often make false or misleading claims based on inaccurate science. There are products for sale that supposedly boost children's intelligence, miracle over-the-counter drugs, therapeutic cosmetics, and more. While the Federal Trade Commission has fined advertisers for such practices, even putting some out of business, the agency cannot hope to police all pseudoscientific claims. Such claims are popular: A recent increase in people touting evidence of aliens visiting Earth reflects acceptance of the idea that non-white people, like the indigenous tribes of the Americas or the ancient Egyptians, were not intelligent enough to accomplish sophisticated technological feats without "outside" help. The list of erroneous "scientific" claims is almost endless.

As the use of social media increases—45% of teens say they are online "almost constantly" (Pew Research Center, 2018)—scientific misinformation spreads faster and further than ever. In face of this competition, teaching accurate information to young people, as schools do, is no longer enough. Science teachers also need to teach students *how to judge* the quality of supposedly "scientific" information they encounter online, on TV or radio, from friends, or anywhere. The proliferation of misinformation has become so serious that, as an editorial in *The Science Teacher* noted, "evidence-based reasoning seems under assault" (Metz, 2017).

On the one hand, according to the authors of *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas* (2012)—which was the template for the NGSS—students should be "careful consumers of scientific and technological information related to their everyday lives" (page 1). On the other hand, this excellent learning goal is not included in the NGSS. In fact, "the NGSS content is focused on preparing students for college and careers" (p. xiii), a distinctly different goal.

Teaching students how to judge the quality of information is distinctly absent from the NGSS. In fact, according to the NGSS, rather than teach students how to systematically weigh evidence about allegedly "scientific" claims they will encounter throughout their lives, science teachers are supposed to focus attention on existing knowledge about a carefully selected set of topics, the DCIs. Anti-vaccination misinformation, the effects of vaping, and how to judge claims about products that supposedly increase intelligence in children are not among those topics.

Even if those specific, timely topics were included in the NGSS, there is now so much scientific misinformation circulating, with new instances arising all the time, that it would be impossible for teachers to "cover" all examples, even the most important ones. And what topics should be left out to make room for a cycling set of dangerous and unscientific claims? Furthermore, teaching students to think critically for themselves about dubious claims should be a core goal of science education. Critical thinking skills can last a lifetime, and can be applied to new claims, "scientific" or otherwise.

If we want students to be smarter about rejecting scientific misinformation we need to teach them how to critically and systematically ask questions about allegedly scientific claims. In collaboration with PBS NOVA staff at WGBH, we developed and tested a one-week unit, *Resisting Scientific Misinformation*, designed to do just that.[iii] The materials are available free online. The following brief description illustrates what is meant by critically thinking about claims allegedly based on science.

The unit is based on peer-reviewed research demonstrating that it is possible to "inoculate" people against misinformation. For example, educating people about misleading argumentation techniques helps to reduce the influence of those techniques (Cook, Lewandowsky, & Ecker, 2017). It is engaging for students to learn about techniques that advertisers, climate change deniers, and others use to mislead people. After all, students don't *want* to be fooled by advertisers or others, and they are exposed to tens of thousands of advertisements.

One basic approach to investigate dubious claims is to teach students not to be a "SAP" by blindly accepting a claim they see, hear, or read, where S stands for *sources*, A stands for *author*, and P stands for *purpose*. Avoid being a "SAP" by asking questions, such as: Who made the claim, and what standing do they have to make claims about science? For what purpose is the claim being made; is it to sell something, to evoke a strong emotional reaction, or to provide information? What sources are cited or are available to bolster the claim?

Answering these types of questions goes beyond rote recall of information, and the answers help separate knowledge from misinformation. Such critical thinking is a core component of what is called media literacy. In an age of social media and rampant misinformation, teaching media literacy is more important than ever in all disciplines, notably including science classrooms. With its accepted methods for verifying claims and building knowledge, science provides an ideal domain for honing the skills students need to be critical users of information.

In a time when fake news can affect elections, many state legislatures—including in Massachusetts, where we live—are considering bills that would require media literacy instruction "across all grades and content areas." This is a compelling idea and we believe that the national science education standards should be revised specifically to help "inoculate" students against scientific misinformation.

Priority Two: Teach Students about Scientific Institutions

The template for the NGSS, *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas* (2012), states:

> "…science is fundamentally a social enterprise, and scientific knowledge advances through collaboration and in the context of a social system with well-developed norms. Individual scientists may do much of their work independently or they may collaborate closely with colleagues" (p. 27).

This is an important idea. In particular, scientific and professional organizations are essential to "obtaining, evaluating, and communicating" science-related information, which is what NGSS identifies as "practice #8," a practice that NGSS says is critically important. To improve the description of that practice we would add the important word *synthesizing*. For example, in epidemiology, practice #8 ideally includes, "obtaining, evaluating *and synthesizing*" multiple studies of vaccines in order to reach sound conclusions, which is one of the functions of the Centers for Disease Control and Prevention

(CDC). As a result, an easy and reliable way to learn about the safety of vaccines is to visit the CDC's website, where expert syntheses are published, including some commissioned by the CDC itself.

However, the NGSS has absolutely nothing to say about scientific and professional organizations, which are essential to science in the 21st century. As far as the NGSS is concerned, students could graduate from high school never having heard of the Centers for Disease Control and Prevention (CDC), the Intergovernmental Panel on Climate Change (IPCC), the Food and Drug Administration (FDA), the American Association for the Advancement of Science (AAAS), or any other science-related organization.

This is short-sighted. For example, it is difficult to imagine teachers doing a good job teaching about climate change, as the NGSS recommends, without talking about the role of the IPCC, which has promoted collaboration among hundreds or thousands of scientists working in multiple specialty areas. Over several decades climate research has been vetted by experts and scientific groups around the world. No individual could possibly do what the IPCC has done. Besides, the IPCC's authority is greatly strengthened because it represents the consensus opinion of so many experts from around the world. Finally, the IPCC can be relied on to provide continual, best-evidence updates of climate change knowledge long after students leave the classroom—contributing to them becoming scientifically informed adults.

As a former President of M.I.T. wrote recently in *Science* magazine, one good way to "get the most from this scientific golden age" is by "recognizing the critical role of institutions in nurturing the scientific enterprise" (Hockfield 2018). Understanding how such institutions work will help students better distinguish authoritative, evidence-based statements from the false mantle of authority assumed by celebrities, politicians or others, many of whom presumably mean well.

A valuable but easy-to-do class assignment for students of almost any age would be to ask them to investigate one of several institutions proposed by the teacher in order to answer questions about the organization. Questions might include: Is the organization public or private? How is it funded? How large is its staff? What is its mission? Does the mission include communicating accurate scientific information to the public, and if so how? As homework, followed by a class presentation and discussion, this assignment would require little time from teachers or students, and yet the assignment could be followed up and reinforced by identifying key scientific organizations throughout the year, relevant to many topics being studied. This type of teaching assignment is appropriate in many scientific disciplines. In short, it is not difficult to teach students about scientific organizations, and such knowledge will yield lasting benefits for students and for science.

Teaching students to resist scientific misinformation, and learning about scientific organizations, are topics so important that they each deserved their own section of this white paper. At the same time, they are examples of a larger "missing piece" of the NGSS, namely scientific literacy and the nature of science, to which we turn next.

Priority Three: Emphasize Scientific Literacy and the Nature of Science

Science content knowledge in the form of the DCIs is central to the NGSS, as seems appropriate. (To repeat an earlier point, even while teaching the "three dimensions" of science, teachers are expected to focus on content from the DCIs.) However, for many decades science educators have written about the difference between knowing science and knowing *about* science. For example, in 1951 James B. Conant wrote in *Science and Common Sense*, "Being well informed about science is not the same thing as understanding science, though the two propositions are not antithetical." The experience of doing science—so important in the NGSS and indeed a major advance over simply learning facts—does not provide sufficient knowledge about science. While individual and class projects can give students a taste of science practices, experiential knowledge needs to be solidified and refined with declarative knowledge. The NGSS gives far too little attention to knowing *about* science, which is as important as knowing science.

Knowing *about* the nature and role of key scientific institutions is part of being scientifically literate, as we noted above. So is understanding peer review and the role of scientific journals, both of which are essential elements of how science is conducted. So is understanding that scientists, even Nobel Prize winners, can be wrong. The idea that science is self-correcting is another key aspect of knowledge *about* science. The importance of replicating results is part of knowing *about* science, as is understanding how disparate scientific disciplines (e.g., astronomy and biology) may use different sets of tools and different standards of evidence. Synthesizing findings across disciplines or specialties, which is critical in so many fields (e.g., climate change), is another important aspect of the nature of science in the 21st century. Knowing at least a little bit about the history of science (such as how and which scientists concluded that the sun and not the earth is the center of the solar system, despite resistance from the church) is also important. (These are illustrative examples of knowing *about* science, not an exhaustive list.)

We agree that the eight "practices" identified in the NGSS, such as "planning and carrying out investigations," are important elements of science and engineering. However, modeling those practices is not sufficient to understand the nature of science, which includes many additional ideas, such as those identified in the paragraph above.

The NGSS includes Appendix H, "Understanding the scientific enterprise: The nature of science in the Next Generation Science Standards." However, there are several problems with Appendix H. First of all, it is unrealistic to assume that teachers trying to teach the "three dimensions" of science at once, often for the first time in their careers, will also pay close attention to each of the NGSS appendices. Besides, Appendix H makes no mention of many important aspects of science literacy and the nature of science, including replication, scientific misinformation, and the role of scientific and professional organizations. Yet, as the NGSS was being developed, the National Science Teachers Association commented that it was important "to make it clear that all students need to understand the nature of science and the history of science." Similarly, according to *A Framework for K-12 Science Education*, students "should come to appreciate that science and the current scientific understanding of the world are the result of many hundreds of years of creative endeavor" (p. 9).

Despite the suggestions noted above from the NSTA and from the NRC's *Framework*, there is nothing in the main body of the NGSS about the history of science, nor about any individual scientist. Nor do the NGSS or Appendix H address the close relationship between science and important public policy issues, such as vaccinations, or keeping our food, water and air safe, or regulating smoking and vaping, or the risks and benefits of nuclear power.

To produce larger numbers of scientifically literate people, a much broader view of science is needed than is offered in the NGSS, with greater attention to knowledge *about* science. If one believes that this broader perspective is important, as we do, then an appendix is not the right place to make that case, even if Appendix H were to be enhanced.

As part of a broader perspective on science, the NGSS should also encourage reading and writing related to science. On the one hand, the NGSS emphasizes science practice #8, "obtaining, evaluating, and communicating information," but on the other hand the NGSS does not ask students to read and then write about newspaper articles, journal articles, or books about science; nor to synthesize information in short oral or written reports about a science-related topic, like the advantages and disadvantages of vaping as compared to smoking tobacco; nor to summarize in writing an investigation of a dubious "scientific" claim. These are missed opportunities for students to read, write and think critically.

The excessively narrow vision of the NGSS contrasts unfavorably with the Common Core, which specifically asks English Language Arts (ELA) teachers to help students make sense of information "in diverse media and sources (e.g., visually, quantitatively, orally) and evaluate the motives (e.g., social, commercial, political) behind its presentation." According to the Common Core, ELA teachers are also supposed to help students make sense of "charts, graphs, diagrams, timelines, animations, or interactive elements on Web pages." All of these goals should be shared by science teachers, too. Furthermore, the Common Core requires "much greater attention" than in the past to reading nonfiction, such as books about science. It is dismaying to realize that the Common Core asks English Language Arts teachers to pay greater attention to having students read nonfiction books, including science, than the NGSS asks of science teachers.

Understandably, many ELA teachers question how they can take on these additional tasks on top of teaching literature and critical writing. Professional developers routinely tell these overburdened teachers that science and social science teachers should take on some of the burden; but standards have been written without logically dividing up responsibility for reading and writing in the disciplines. Reading and writing about science are such important skills that science teachers should be guided to include them as part of their teaching practice. After all, for most citizens, reading about science will be a major way that they maintain scientific literacy throughout adulthood, while those students who go into science careers may well find more than half their time devoted to reading and writing about science.

As another example of a broader approach, many English and History teachers use movies to interest students and to provide a different, often interdisciplinary, perspective on their subjects. Movies can be used to accomplish similar goals in science classes. In the case of the recent Academy Award winning movie *Hidden Figures*, as an example, the movie could be used to begin a class discussion about the representation and role of women and minorities in scientific and technological careers—an issue that is almost universally considered a significant national need. The main body of the NGSS has nothing to say about the role of women and minorities in science, and Appendix H merely notes that science and technology are disciplines conducted by a variety of people.

The chance to encourage STEM teachers to take a broader view of science, as described above, represents a missed opportunity. The NGSS's narrow vision of science ignores ideas and approaches that would almost certainly interest more students in STEM subjects while also producing a more scientifically literate citizenry.

Priority Four: Introduce Some Key Principles of Teaching and Learning

Once upon a time, not long ago, many educators believed that teaching young people accurate science would be enough; students would grow up believing what scientists have learned about the natural world. Today we realize that such a point of view is too simple and over-optimistic.

Arguably the most famous video footage in science education is in *A Private Universe*, a twenty-minute film produced in 1981 (and free online[iv]). The opening minutes of the video show young people dressed in academic robes at a Harvard graduation. Despite their expensive, prestigious educations, many of the graduating seniors cannot correctly explain why the Earth has seasons—a concept taught to virtually every young person. *A Private Universe*, as well as thousands of peer-reviewed research studies, along with later science education videos (e.g., *Minds of Our Own* [1997] and *Good Thinking* [2015]), present and explore the difficulty and the importance of dislodging students' misconceptions about a wide variety of science topics, rather than merely teaching accurate science.

The goal of working to reduce student misconceptions is related to the goal of teaching students to investigate scientific misinformation. In each case, students must be able to think clearly to separate true claims from false ones, despite the fact that misinformation may be appealing and even seem intuitively to be correct.

With regard to the seasons, a misconception held by a great many people is that the Earth is warmer in the summer because it is closer to the sun. But if that were really the reason why it's hot in the summer, say in the northern hemisphere, then why is it simultaneously cold in the southern hemisphere? And how can there be summer in the southern hemisphere six months later, when Earth is supposedly farther from the sun?

Researchers have concluded over and over again that it is counter-productive to ignore common student misconceptions—about seasons, or the motion of objects and Newton's Laws, heat and temperature, eclipses, or countless other scientific phenomena. Scientific misconceptions have a tendency to disappear for a short time when students learn to parrot right answers, and then to reappear later, as vividly illustrated in *A Private Universe*. To dislodge a misconception, teachers—even professors at the university level—are advised to focus students' attention first on an important misconception and then explore the reasons why it is not true.

There is probably no aspect of science education with a deeper research base than students' erroneous preconceptions about phenomena. However, the NGSS does not bring this topic to the attention of teachers who read the document. In volume one of the NGSS, which is more than 300 pages long, there is not even a reference to any publication about learning science—not *How People Learn*, or *Taking Science to School: Learning and Teaching Science in Grades K-8*, or *Learning and Understanding: Improving Advanced Study of Mathematics and Science* (all published by the National Research Council). Nor do the words "misconception" or "preconception" appear in that volume (except one reference to misconceptions about technology).

The absence from the NGSS of ideas about learning, or even references to pertinent publications, is surprising because scientists themselves know how important it is to teach with students' misconceptions in mind. Professors such as Helen Quinn (Stanford), Nobel Prize winner Carl Wieman

(University of Colorado for many years), and Eric Mazur (Harvard) are among the distinguished scientists who have contributed to knowledge about how students learn science.

Think about elementary school teachers, who usually teach science in addition to many other subjects, and whose own knowledge of science is often limited. Do authors of the NGSS imagine that these teachers will study and absorb volume after volume of education standards related to reading, writing, mathematics, history, social studies, science, and other topics (e.g., financial literacy, media literacy), and then go further by reading ancillary works for each set of standards, such as the NGSS appendices, and then—that not being enough—read whole other volumes such as *How Students Learn*? One could test that belief with a survey of teachers or school principals, but it seems unrealistic, on the face of it, to leave important ideas out of the NGSS and expect teachers—and curriculum developers, and test developers, and state and local policymakers—to pay equally close attention to the ideas in ancillary materials as to what is included in the NGSS itself.

It would be simple enough to include in the NGSS a few paragraphs referencing the importance of attending to students' misconceptions, briefly advising teachers how to deal with misconceptions more effectively, and then referencing *How People Learn* or other relevant publications. It would not be the first time that a set of education standards discusses teaching and learning. Notably, the *National Science Education Standards*, predecessor to the NGSS, included a chapter about science teaching standards and another chapter about teacher professional development.

Returning to the idea that teaching what scientists know is not enough, it has also become clear that reciting the right answer about a scientific question is not the same as accepting the information as true. Social science research demonstrates that cultural factors—notably the "tribes" we each belong to—are now more significant predictors of accepting or rejecting scientific misinformation than scientific knowledge by itself. One can appreciate this finding by realizing that climate change denial, anti-vaccine beliefs, and rejection of human evolution, to name a few examples, are beliefs found even among apparently well-educated people.[v] The NGSS needs to place more emphasis on the psychology of teaching and learning in part because in our more polarized society, where many experts—scientists included—are no longer held in high regard, it is more important than it was decades ago that students learn *why* scientists believe what they believe, *how* they reach sound conclusions, *what* are reliable sources of scientific information, and *how* to think about questionable "scientific" claims, even ones that seem intuitively obvious (like Earth supposedly being closer to the sun in the summer).

In focusing so much attention on the DCIs, and ignoring misperceptions, misinformation, and key aspects of the nature of science, the NGSS in effect embraces old-fashioned theories of learning science. One of those theories is sometimes referred to as a "knowledge deficit model," which suggests that if we teach people the scientific facts they need to know then they will retain them, understand them, accept them, and reach correct conclusions based on those facts. There also seems to be an assumption that students will accept scientists' conclusions about important matters that are not included in the NGSS, like vaccine safety, even though students are not explicitly taught how to use evidence and reasoning to investigate claims they have not studied.

Given the growing importance of scientific misconceptions and misinformation, relying on outdated theories about science learning, and not alerting teachers to well-established knowledge about misconceptions in science, is not the best way to create a scientifically literate population. The NGSS should include some information about how students learn science and when they are likely to trip up.

Discussion and Next Steps

Students might study science for twelve years in high quality programs carefully aligned with the NGSS, graduate high school, and not have been asked to do any of the following things:

- Examine their own scientific misconceptions, such as that summer is caused by the earth being closer to the sun;
- Investigate a dubious scientific claim, or distinguish reliable sources of scientific information from unreliable sources;
- Learn the name or function of any scientific or professional institution;
- Write about a book or a movie focused on science, or summarize a newspaper article or scientific journal article about science or engineering;
- Synthesize information about an unfamiliar science topic, like the safety of vaccines or of vaping, and report on or write about what they learned;
- Study immunity, immunizations, or vaccines;
- Learn how science is used in making public policy, and by whom;
- Learn about the capabilities and under-representation of women and minorities in STEM fields;
- Learn almost anything about the history of science, not even the name of an important scientist;
- Learn important aspects of the nature of science, such as the value of replication, or that distinguished scientists are sometimes wrong (and science will later correct such errors), or that cutting-edge science typically requires the expertise of many specialties.

Eliminating so much potentially rich material from the curriculum reflects an extremely narrow vision of what students ought to know about science. To become scientifically literate adults, students need a broader view of science. In light of these concerns, it is time begin considering how to revise the NGSS to make the standards better, both for those students whose careers will involve science or engineering and for the larger number of students whose careers will not involve science or engineering.

As mentioned on page 11, the *National Science Education Standards* (1996) included chapters about teaching science as well as about teacher professional development. In addition, that earlier publication included content standards about the history and nature of science, as well as about science in personal and social perspectives. It seems likely that the reason developers of the NGSS eliminated so much material was to limit the content covered in the new standards, an admirable goal. However, in the process of emphasizing depth over breadth, we believe too many important matters were eliminated. The proverbial pendulum was moved to the other extreme, not to an appropriate middle point.

In developing the NGSS we wonder whether important voices were missing, such as representatives of the PTA, public health officials, state legislators, members of local school boards, pollsters who know a great deal about public understanding of science, or others whose perspective on science is different from scientists' and who might contribute ideas regarding what adults should know about science, regardless of their career. Whenever the NGSS goes through a formal revision process, it would be useful to include people with a broader perspective, the perspective of what one might call "users of science in everyday life."

Let's imagine a simple fix or patch that would greatly improve the NGSS, or state science education standards based on the NGSS. For sake of argument and simplicity one could leave the DCIs, the practices, and the cross-cutting ideas untouched.

Adding a short section of a few pages to the NGSS could accomplish a great deal. Perhaps this would be a preface. Keep in mind that the printed version of the NGSS is over 300 pages long and adding, let us say, six pages would increase the length by only two percent.

The new section could first focus on a few key principles of teaching and learning science, notably the importance of teachers explicitly recognizing students' preconceptions and misconceptions. References would be included to a few key sources pertinent to teachers who seek further information. Adding even one page about teaching and learning science would be an improvement over what is now in the NGSS.

The major focus of the added pages would be on expanding the expectations expressed in the NGSS. It might say that each year about 10% of the time spent teaching science should be devoted to scientific literacy topics, including: scientific misinformation; how to judge the accuracy of scientific claims (including which sources of information are more or less reliable, and why); the role of scientific institutions in gathering, evaluating, synthesizing and communicating knowledge; the history of science; public policy issues involving science; and reading and writing about science.

Many of these topics can be integrated into existing lessons. Undoubtedly some teachers already do, but the goal is for far more teachers to do so. Some state agencies, teacher professional organizations such as the NSTA and its state affiliates, and many commercial textbooks already provide a variety of lessons that focus on important aspects of scientific literacy not specifically included in the NGSS. Instead of implying that such lessons are inappropriate or less important than what's included in the NGSS, we believe that policymakers, and ultimately science education standards documents, ought to encourage teachers to include more high quality lessons focused on scientific literacy.

With this proposed broader focus on science, some new lessons would not be perfectly aligned with the NGSS in its current form, or with an existing science textbook, or with a high-stakes state test. Ultimately, of course, we would like to see science textbooks and tests revised to reflect the broader goals of scientific literacy that we have described above. However, it would be a shame to wait many years or a decade for that to happen. That is why we propose adding a few pages to national or state science education standards as soon as is feasible.

Although the *Next Generation Science Standards* may not be revised for years, it is not too soon to examine its impacts and to discuss opportunities to improve the standards.

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Endnotes

[i] Arkansas, California, Connecticut, Delaware, Hawaii, Illinois, Iowa, Kansas, Kentucky, Maine, Maryland, Michigan, Nevada, New Hampshire, New Jersey, New Mexico, Oregon, Rhode Island, Vermont and Washington.

[ii] The 21 states are Alabama, Arizona, Colorado, Georgia, Idaho, Indiana, Louisiana, Massachusetts, Mississippi, Missouri, Montana, Nebraska, New York, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, and Wyoming.

[iii] See https://tumblehomebooks.org/services/resisting-scientific-misinformation/

[iv] *A Private Universe* can be viewed here, free: https://www.learner.org/resources/series28.html#

[v] Because this paper is not a scholarly treatise we are not citing most of the many references supporting the idea that teaching scientific knowledge, per se, is not enough. Here are two references; the first one concerns climate change: Kahan, D.M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change* 2: 732-725. The second reference concerns health information: Carroll, A.E. (July 22, 2019). Health Facts Aren't Enough. Should Persuasion Become A Priority? *The New York Times.*